InnovationXLab CarbonX Summit

Carbon in the Digital Era: Artificial Intelligence & Machine Learning

Thursday, October 22, 2020

Moderator
Cheryl Ingstad

Director,
DOE-Artificial Intelligence &
Technology Office
Department of Energy

Panelist
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Senior Fellow,
Geological &
Environmental Systems
National Energy
Technology
Laboratory

Panelist
Shannon Katcher

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Digitalization & Data
Gas Technology
Institute

Panelist
Dr. Jeffrey Yarus

Professor, Department of
Materials Science and
Engineering
Case Western Reserve
University

InnovationXLab CarbonX Summit

Carbon in the Digital Era: Artificial Intelligence & Machine Learning

Panelist

Dr. Grant Bromhal

Senior Fellow,
Geological & Environmental Systems
National Energy Technology Laboratory

Leveraging DOE's Capabilities for the "Digital Oilfield"

Grant Bromhal, Senior Fellow for Geosciences

Jared Ciferno, Upstream and Midstream Technology Manager

Carbon in the Digital Era: AI & ML Panel

2020 Virtual DOE InnovationXlab CarbonX Summit

NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. DEPARTMENT OF ENERGY

Traditional Oil & Natural Gas Exploration and Development

Traditional industry focus has been on maximizing production of high-value oil & natural gas in traditional reservoirs

ONSHORE

Conventional Oil & Natural Gas Development

https://link.springer.com/article/10.1007/s13202-017-0395-2

- Field Development
- Large-scale Full Physics Modeling
- Exploratory Drilling

OFFSHORE

Gulf of Mexico or Outer Continental Shelf

Unconventional Oil & Natural Gas Exploration and Development

Modern Hydraulic Fracturing techniques in unconventional reservoirs have enabled enhanced development and have acquired more data than can be analyzed by current modeling and simulation methods.

- Initial completion techniques in a new play are highly inefficient
- New practices evolve primarily through trial and error
- Thousands of wells may be needed before standard is developed
- Vast majority of oil and gas is still left in the ground

A significant amount of data goes unused which likely results in lower production efficiency

Transitioning to a "Digital Oilfield"

What are the benefits of transitioning to a "Digital Oilfield"?

High-Priority Use Cases

Field Development

Fracture Modeling

Completions Design

Enhanced Oil Recovery

Well Design

Water Management

Reservoir Modeling

Reservoir Characterization

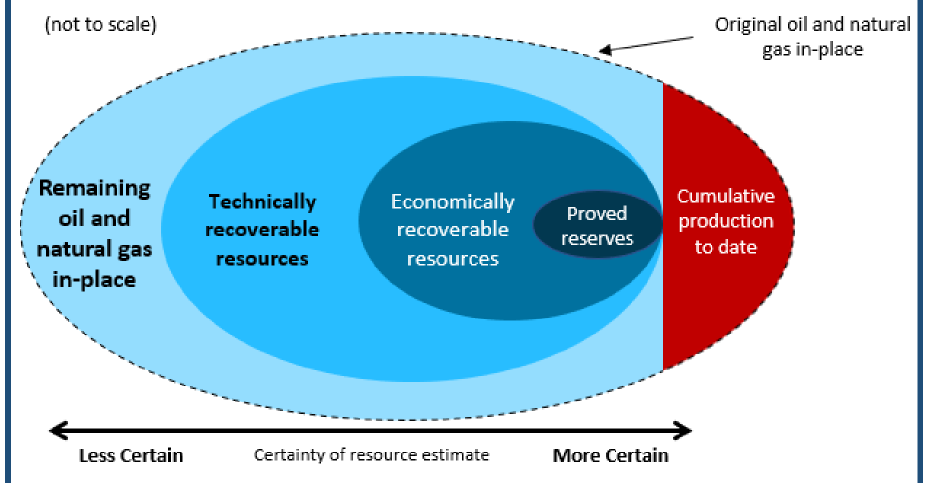
Associated Gas

Well Shut-Ins

Increase Recovery Efficiency

- Current Estimated Primary Recovery is at **10% - 12% for most Unconventional**
- Production rates can drop by 50% in first year

Stylized Representation of Oil and Natural Gas Resource Categorizations



Source: Adapted from U.S. Energy Information Administration
Note: Resource categories are not drawn to scale relative to the actual size of each resource category. The graphic shown above is applicable on to oil and natural gas resources.

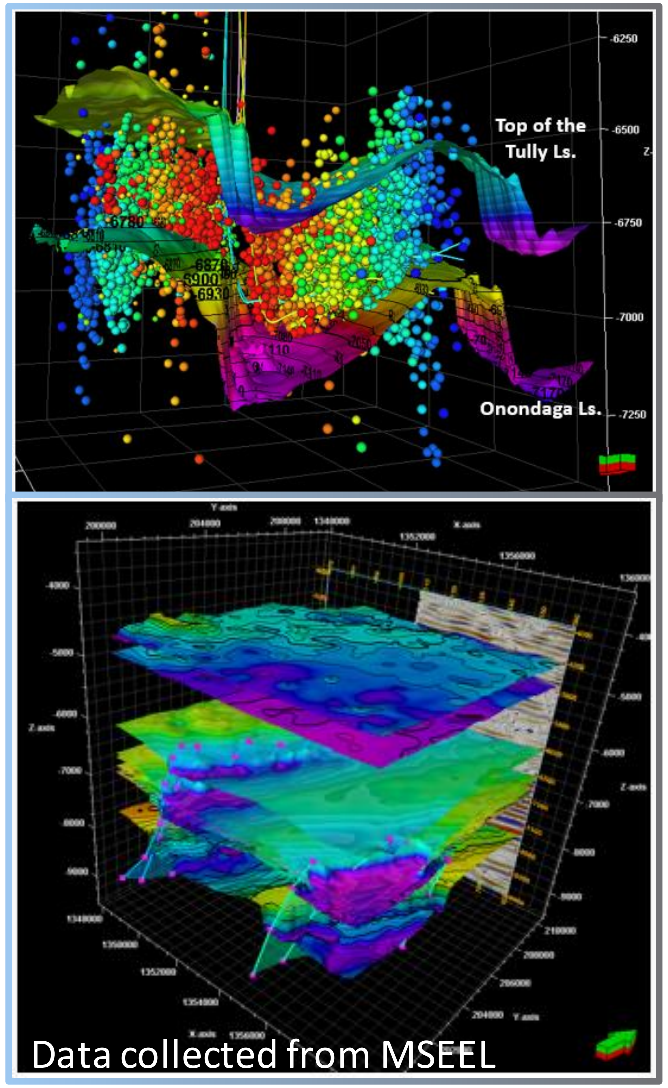
Improve Environmental Stewardship

- Reduce physical footprint
- Improve water management
- Emissions reduction

Digitalization Opportunities w/NLs

- Integration of multiple dense and real-time data sets
- High performance computing resources
- Application of AI/ML technologies

NLs uniquely suited to exploit new sensing technologies

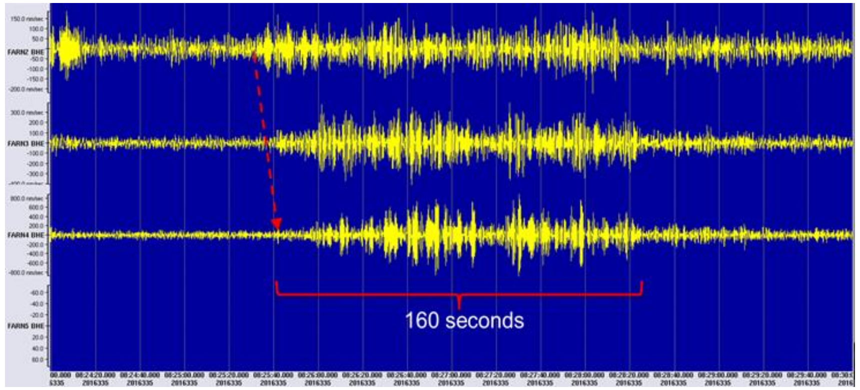


Data collected from MSEEL

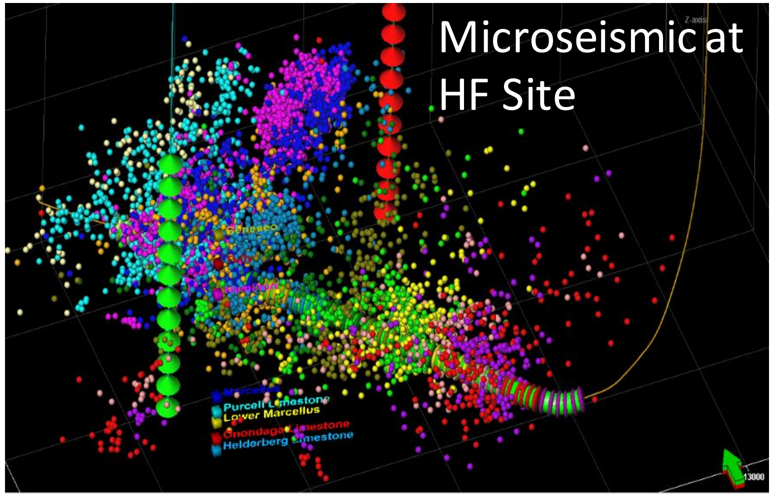
Large data collection rates and volumes

Fiber optics sensors
Microseismic data
Injected micro- and nano-sensors
Stage-specific production data

- Sensor deployment best practices
- Joint inversion of multiple data streams
- High-fidelity modeling
- Application of machine learning



Seismic Tremor at EOR Site



Microseismic at HF Site

ML used to identify source, improve locations

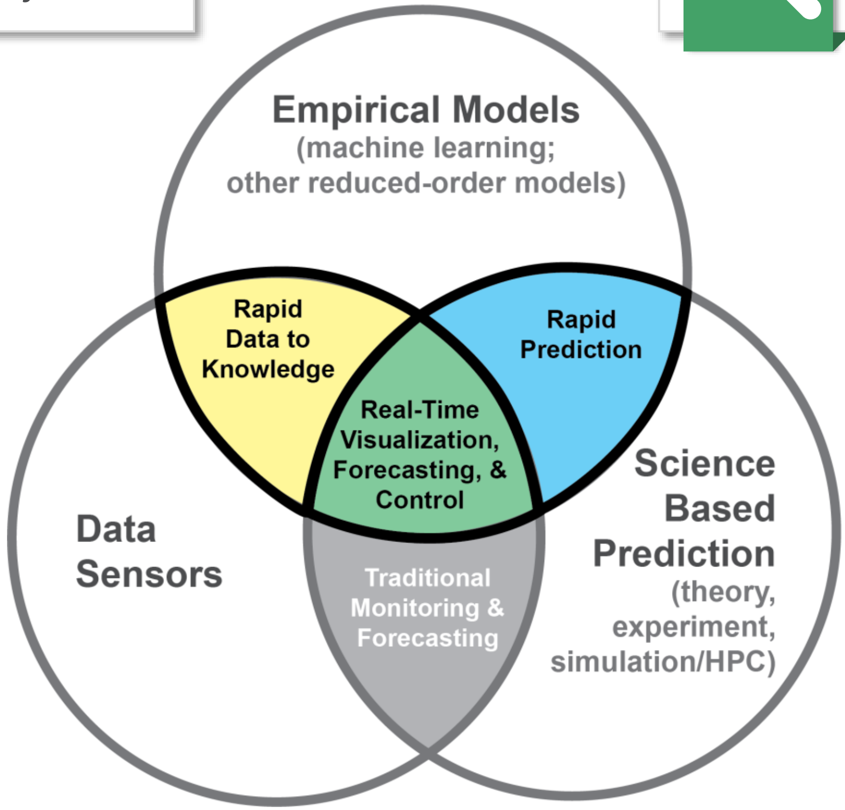
Confluence of Sensing, Computing, and ML

Real-Time Visualization
"CT" for the Subsurface

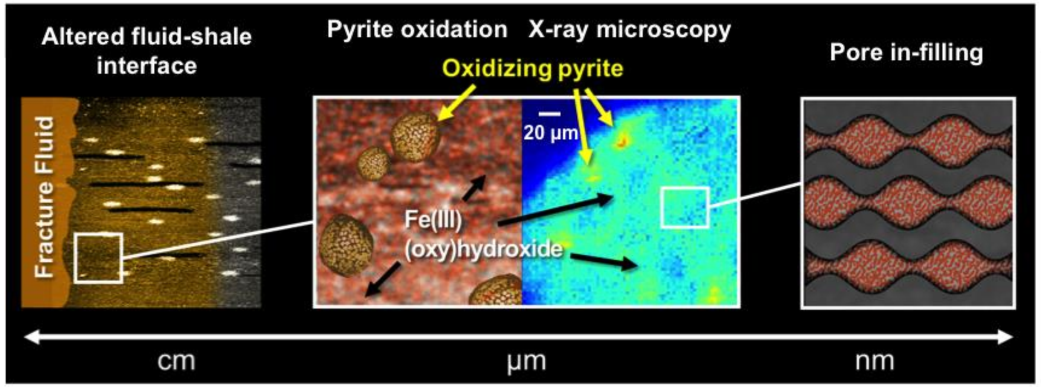
Real-Time Forecasting
"Advanced Control Room"

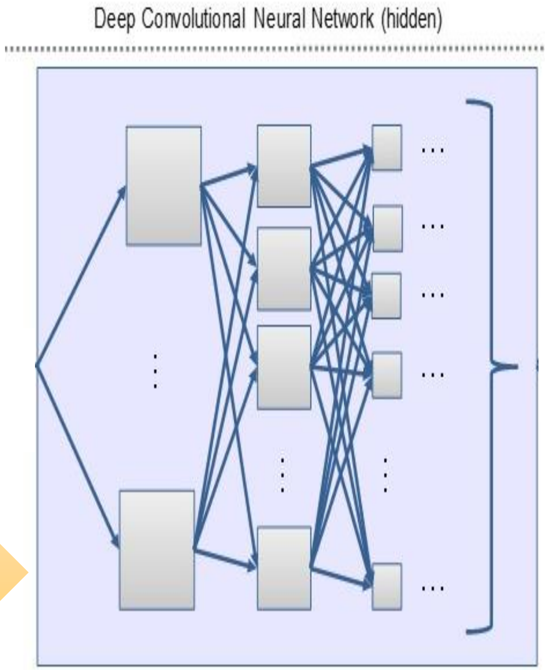
Rapid Data to Knowledge
Autonomous Monitoring

Rapid Prediction
Virtual Learning



Enabled by Fossil Energy Investments





Fundamental Studies

Industry collaborations

Academia

DOE Labs

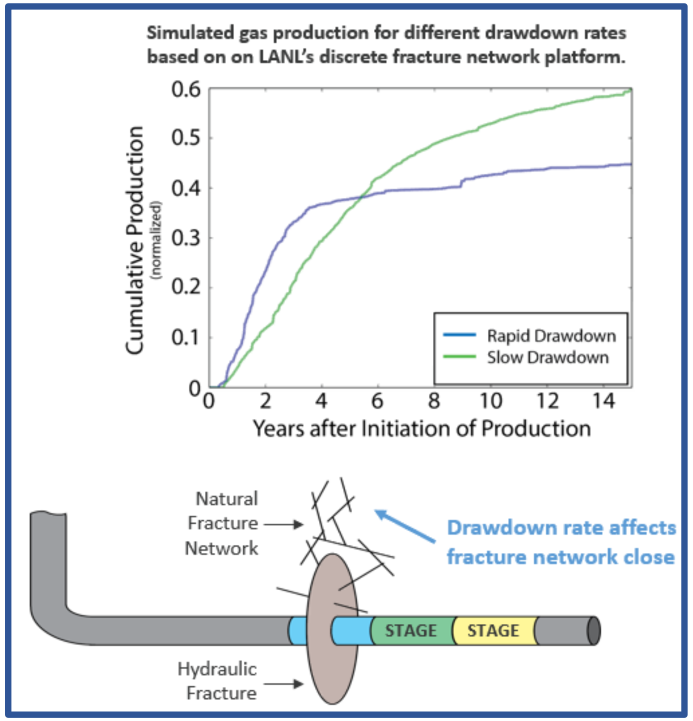
Field Laboratories

Data-Driven Approaches

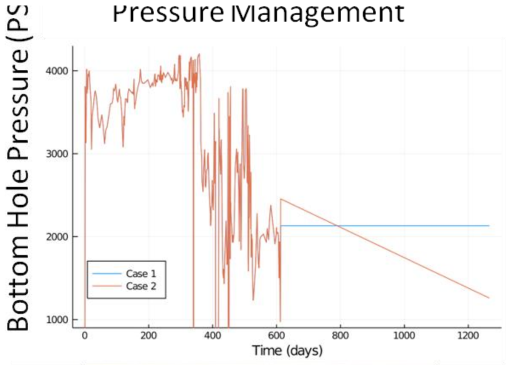
More than 40 recent field projects

Real-time Simulation of Production

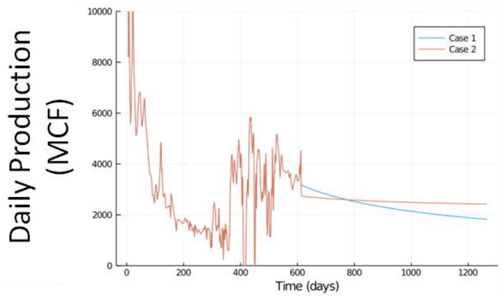
MSEEL DOE Field Site



Real-time Pressure Management Dashboard



Operational Parameters



Baseline

Managed

+4% Ultimate Recovery

U.S. DEPARTMENT OF ENERGY

From: Viswanathan, Guthrie, Carr et al, 2020.

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Thank You!

Science-informed Machine Learning to Accelerate Real Time (SMART) Decisions in Subsurface Applications

Real-Time Visualization
"CT" for the Subsurface

Rapid Prediction
Virtual Learning

Real-Time Forecasting
"Advanced Control Room"

Enabling better decisions given scarce resources in a highly uncertain subsurface.

Technical Team

Carnegie Mellon University
Los Alamos National Laboratory
National Energy Technology Laboratory
Battelle
EERC University of North Dakota
FACT
Lawrence Livermore National Laboratory
Colorado School of Mines
Oak Ridge National Laboratory
PennState
The University of Utah
Pacific Northwest National Laboratory
Bureau of Economic Geology
Sandia National Laboratories
Illinois University of Illinois at Urbana-Champaign
Berkeley Lab

InnovationXLab CarbonX Summit

Carbon in the Digital Era: Artificial Intelligence & Machine Learning

Panelist

Shannon Katcher

Executive Director,
Digitalization & Data
Gas Technology Institute

MANAGING CARBON, GROWING ECONOMIES

Leveraging Data and Analytics to Enable Transition

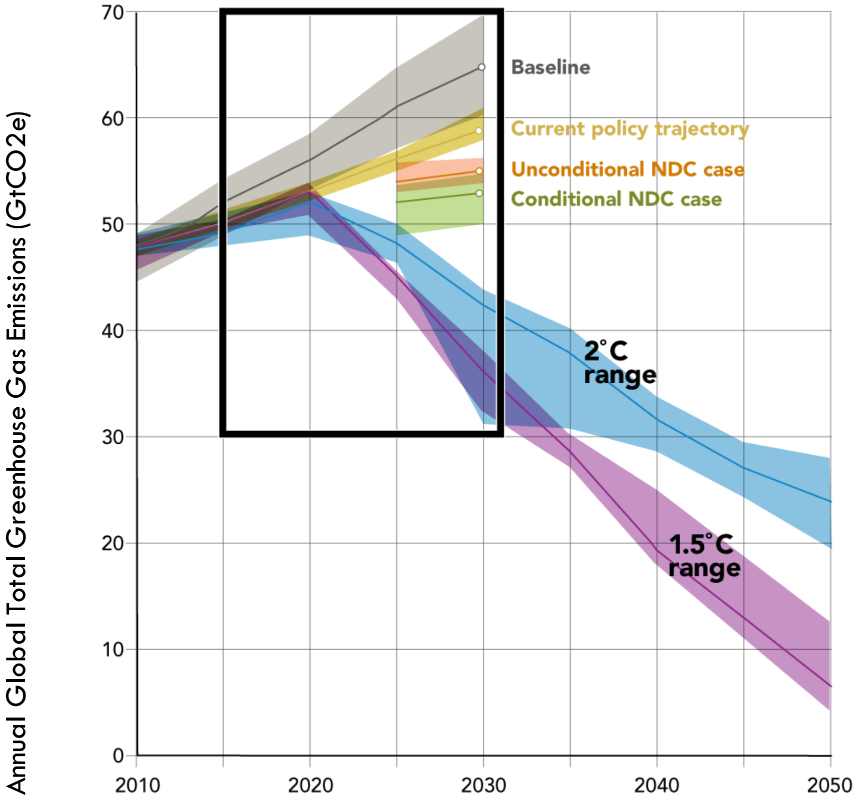
GTI's Vision for Transitioning to Low-Cost, Low-Carbon Energy Systems in 2030 and Beyond

GTI is a not-for-profit R&D organization with a nearly 80-year history of developing clean energy technologies.

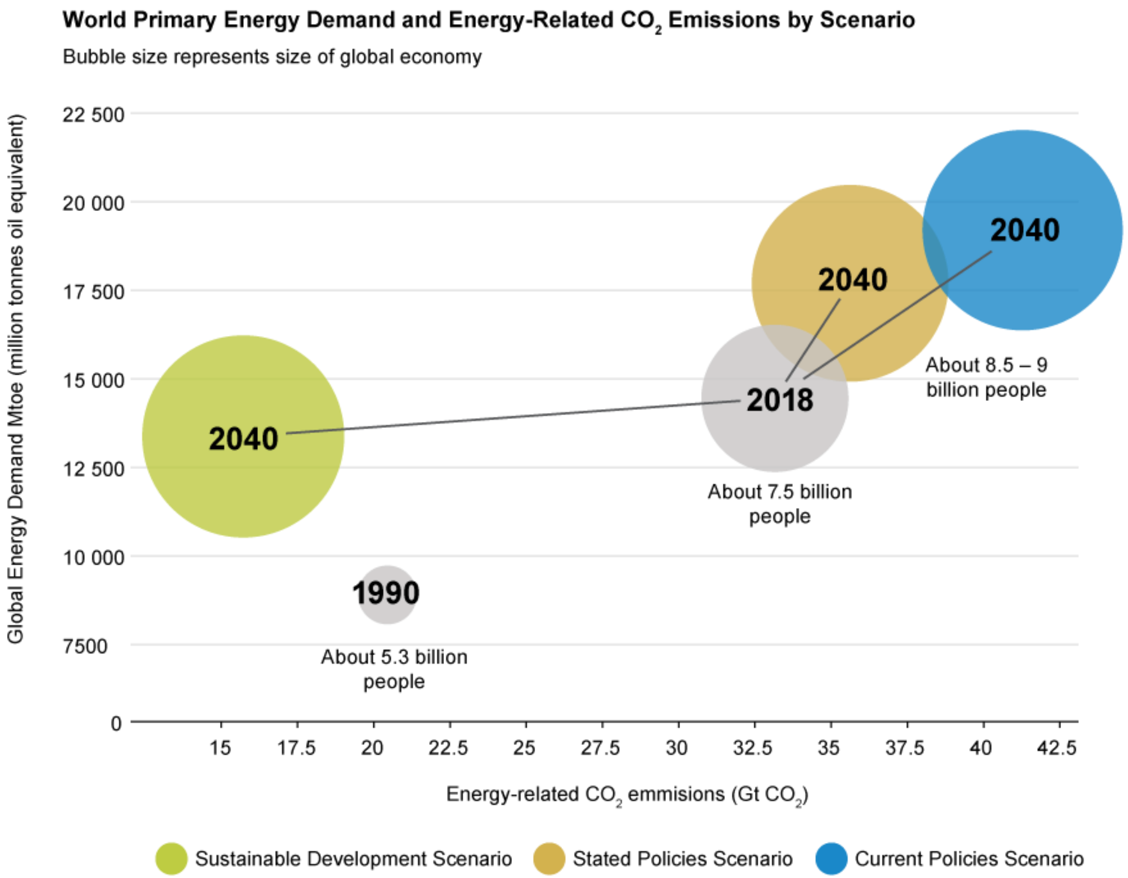
GTI envisions a carbon-managed future in which integrated energy systems leverage low-carbon or carbon-neutral fuels, gases, and infrastructure to limit global temperature rise.

DUAL IMPERATIVES

We must both decarbonize energy systems AND supply the energy needed to support economic growth around the world.



&



Sources: United Nations Environment Program (UNEP) 2017 Emissions Gap Report (left); International Energy Agency (right)

EXPANDING INTO THE FUTURE

Digital data and advanced analytics will drive us into a smarter future

New Assets/ Infrastructure

Tailor Asset Mix
- Hydrogen
- Other Alternative Energy

Rethink Energy Business
- Optimize Value Chain
- Enabled by Digital Infrastructure

Existing Assets/ Infrastructure

Maximize Today's Potential
- Increase Resilience & Reliability
- Improve Operations via Data Automations

Rethink Operating Model
- Advanced Analytics/AI/Machine Learning
- Cybersecurity

Existing Operations

New Operations

Image reimagined from:
https://www.energytoday.net/conventional-energy/the-energy-company-of-the-future-an-existential-crisis-for-oil-and-gas-companies/

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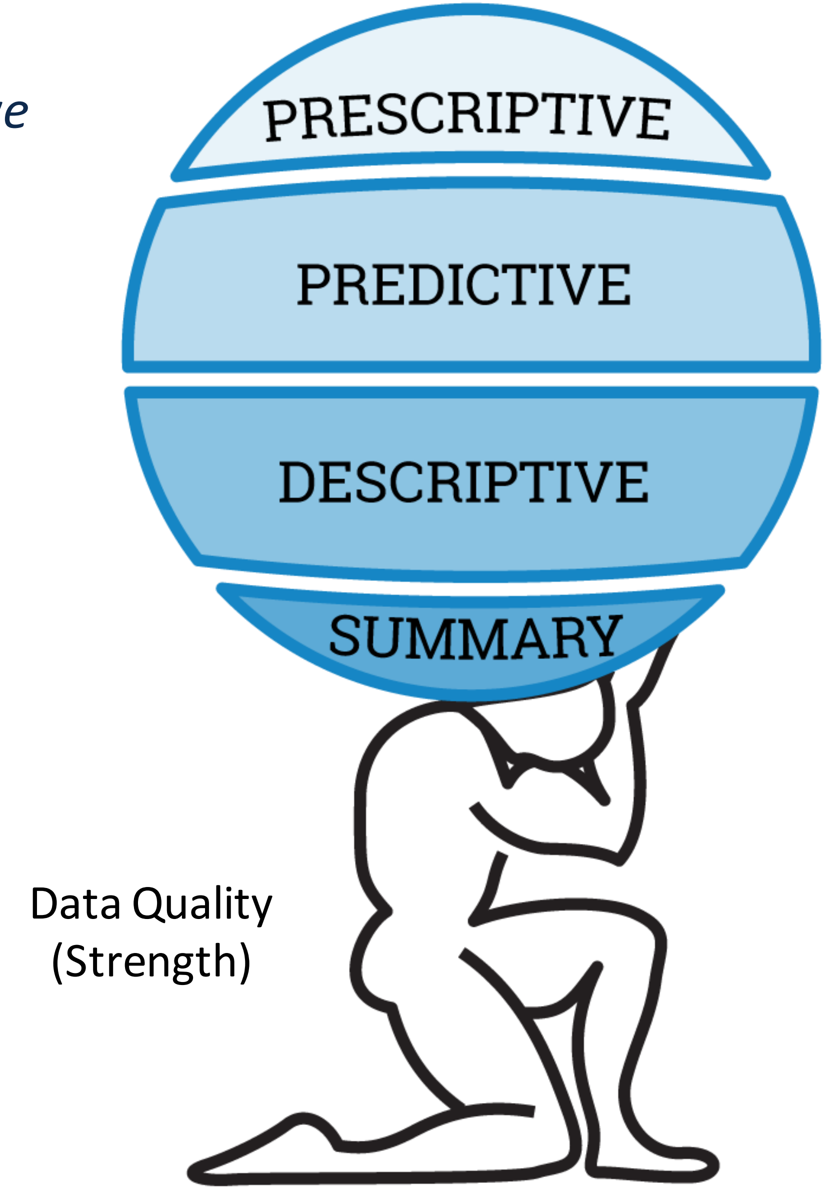
INNOVATION REQUIRES DATA

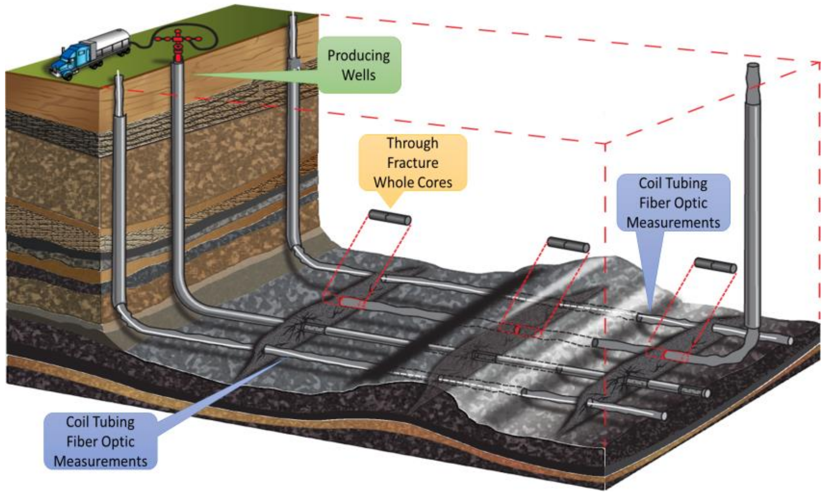
Analytical capabilities are restricted by the data we have available to us

Growing Analysis Burden
Value increases as complexity increases

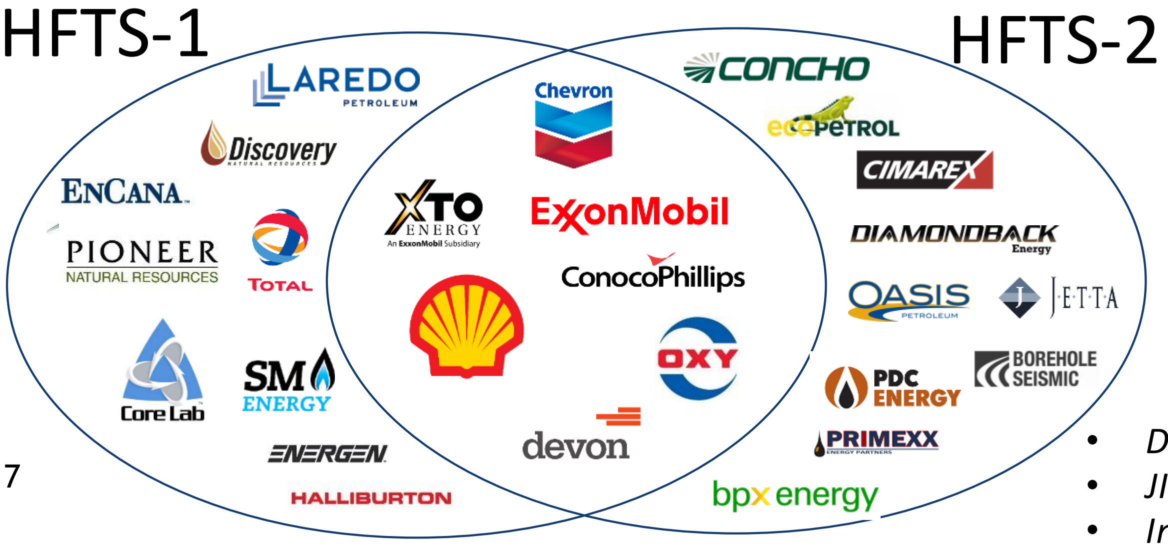


HYDRAULIC FRACTURING TEST SITE (HFTS) PROGRAM

Digital data and advanced analytics will drive us into a smarter future



Post-fracture slant core well – the only existing ground truth of actual fracture geometry. That data lead to conclusions that would have never been predicted by existing commercial fracture simulators.



- *DOE Funding - $20 million*
- *JIP Co-funding - $53 million*
- *Industry in-kind - ~$600 million*

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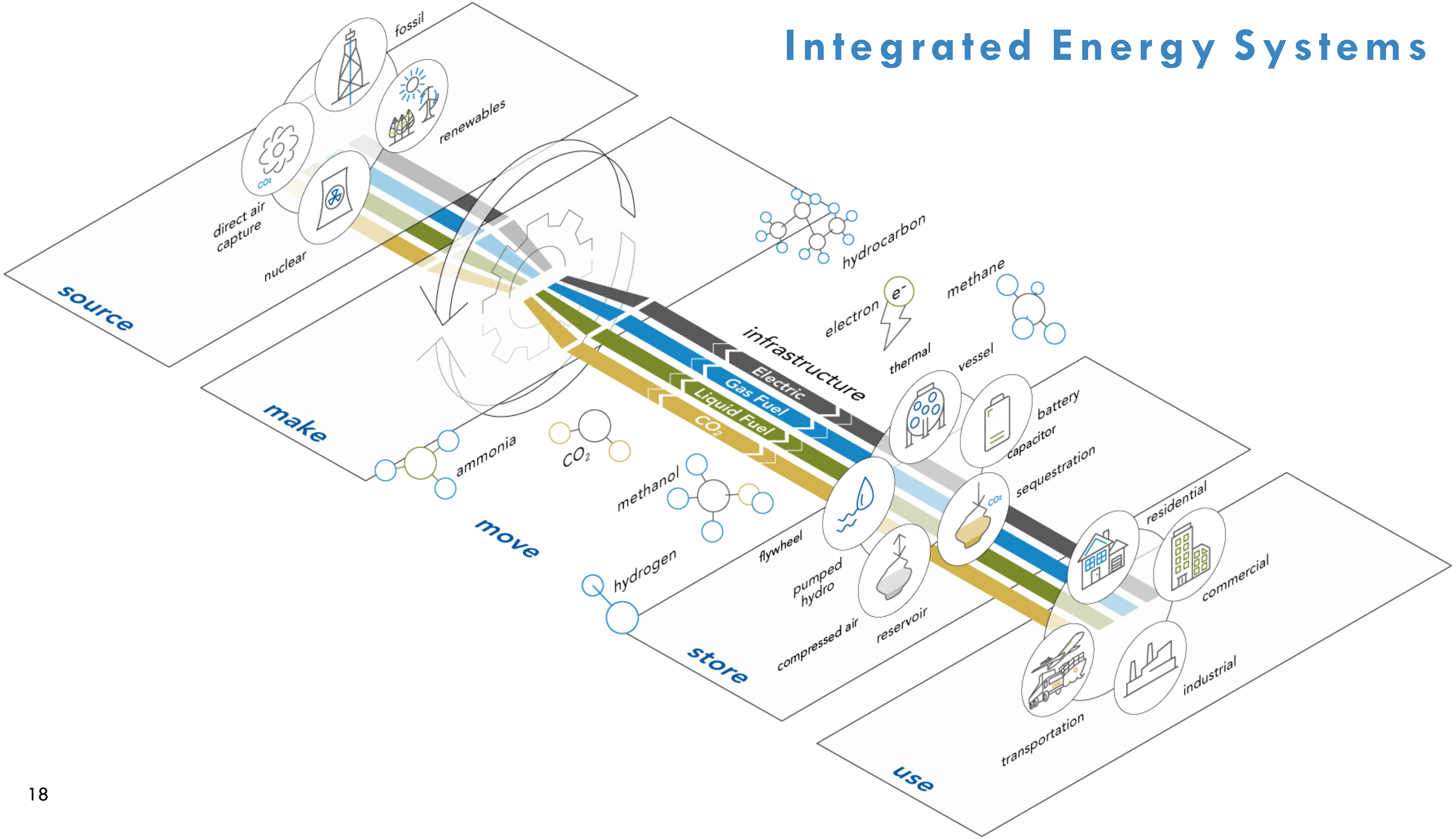
Integrated Energy Systems



Integrated Energy Systems

SunGas RENEWABLES

HyPER

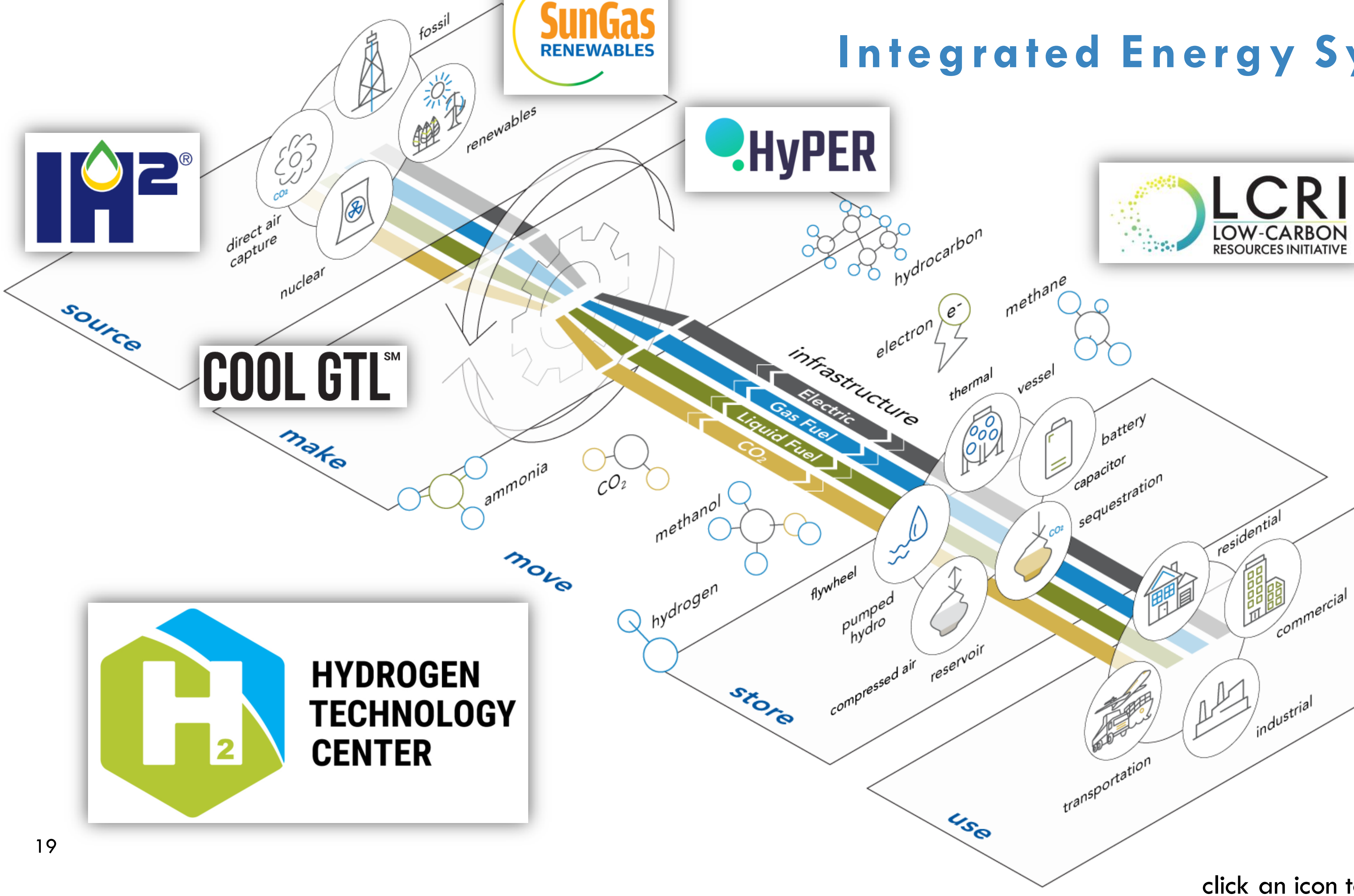
LCRI LOW-CARBON RESOURCES INITIATIVE

EPRI ELECTRIC POWER RESEARCH INSTITUTE | gti

COOL GTL℠

California FUEL CELL PARTNERSHIP DRIVING FOR THE FUTURE

HYDROGEN TECHNOLOGY CENTER



click an icon to learn more

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Thank You

Shannon Katcher | 847-544-3492 | skatcher@gti.energy | www.gti.energy

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Panelist

Dr. Jeffrey Yarus

Professor,
Department of Materials Science and Engineering
Case Western Reserve University

Advancing Technologies in Computational Earth Models;

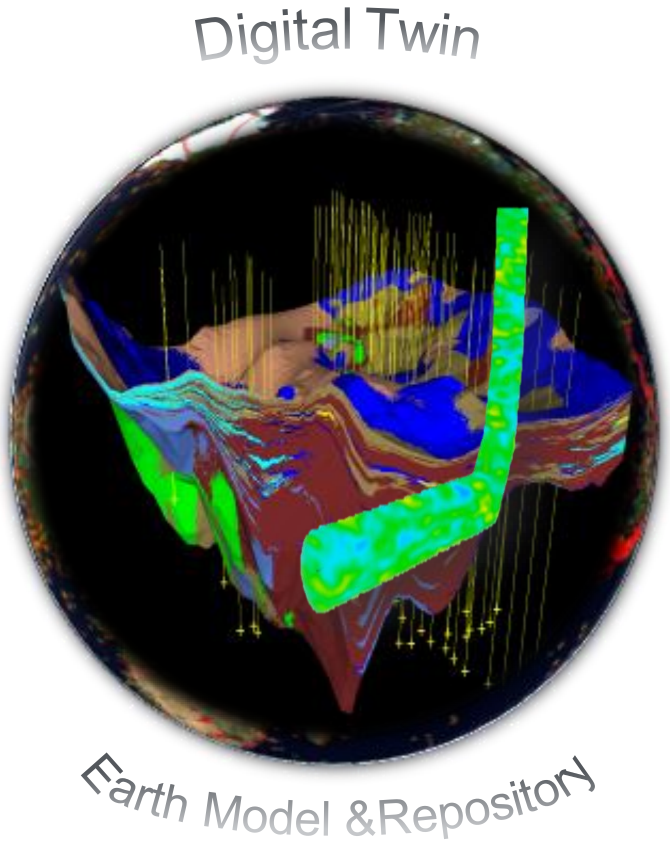
Spatial Modeling in the Near Surface, Surface and Subsurface

Jeffrey M. Yarus
Professor, Case Western Reserve University
Halliburton Technology Fellow, Retired

What Are Computational Earth Models?

Quantitative representations of the earth's near surface, surface, and/or subsurface

Think:* *Size, Shape, Orientation, Composition, Internal Arrangement
Fill the inter-sample space (1D, 2D, 3D, ND)



- Subsurface Digital Twins:
- For the purpose of:
  - Education
  - Research
  - Commercial Enterprise
  - Public Policy

- Built from a variety of data sources
- Interrogated and consumed by a variety of disciplines and sub-disciplines
- Provides a quantitative assessment for the public or private industry

How we got to where we are… Key Publications and Technologies

The evolving Earth Model

<

1950 1960 1970 1980 1990 2000 2010 2020 2030

Nicholas Steno, 1669 Original Horizontality

James Hutton, 1785 Principles of Uniformitarianism

~1800, Stratigraphy

William Smith, 1815

Charles Lyell, 1830 Principles of Geology

Charles Picquet, 1852, Geography

Leverett, *1941 Capillary Pressure*

H.J. De Wijs Statistics of Or Distributions, 1951-1953

D.G.Krige's work on Support, 1951

H.S. Sichel, log normal distribution in gold mines 1947

Matheron begins Regionalized Variable theory

1955 Term, Geostatistics" first used

Term "Krigeage" first used, Calier

John C. Griffiths 1951, Size versus Sorting

Andrey Kolmogorov, 1949, probability and the formation of strata

Polynomials for data fitting, digital computer, Forsythe, 1957

Peaceman *~1955*

Geostatistics

Linear Geostatistics

Geoanalytics

Geoengineering

Roger Tomlinson, 1963 GIS

Term "Kriging" first used, Matheron, 1962

Computer Applications, Harbaugh, Merrium, 1968

Computer Mapping

Contouring by Triangulation, Davis, IBM, 1964

Krumbine and Sloss 1963 Progressive Linear Fit of Surfaces, Cole, Jordan, Merriam, 1967

How long is the cost of Britain?, (Fractals) 1967

Automated Contouring of Irregularly Spaced data, Pelto, Elkins, Boyd, 1968

Yee, FDTD *1966*

Center of Geostatistics, 1968

Matheron Completes Regionalized Variable theory

1963 – 1969, GIS

Jack Dangermond, 1969 ESRI

John C. Griffiths 1967, Scientific Methods, Sediments

Porous Media (Boolean Modeling), Matheron, 1970

Interpolation with Splines, Agterberg, 1967

Koch and LInk, 1970

Hass and Viallix, 1976

First geostatistics applications in the oil industry

Delhomme and Giannesini, 1979

Non Linear Geostatistics

Matheron works on UK, IRFK, DK, 1973

Matheron conditional simulation TBS, 1972

Krigpac, 1976

Lognormal Kriging, Matheron, 1974,

Turning Bands Simulation, Journel, 1974,

Surface II, 1970-1975

Geomathematics Agterberg, 1974

Geologic Factor Analysis, Joreskog, et.al., 1976

Computer Software for Geosciences, 1974

Statistics and Data Analysis Davis, *1973*

Minimum Curvature, Briggs, 1974

1st commercial Simulator, *~1975*

Compositional simulation *Peng-Robinson & Soave-Redlich-Kwong~1972-76*

Delfinier/Chiles Conditional Simulation

ARC/INFO, 1981

Bluepack, 1978 Magma, 1980

Mining Geostatistics, Journel and Huijbregts

Heresim 2D, 1983

ZMAP, 1983

RockWare, 1983

Surfer, 1983

Eclipse 1st commercial Release, *1983*

Gohfer, *~1983*

SedSim, 1989

Applied Geostatistics Isaaks & Srivastava, 1989

Multipoint Simulation, Guardiano & Srivastava, 1992

Truncated Gaussian Simulation, 1987

Matheron works on Information Effect, 1984

SIS, Journel, Isaaks, 1988-89

ISim3D 1988

Heresim 3D, 1992

Isatis, 1993

goCad Consortium, 1989

RC², 1992

IRAP, 1990

Geolith, 1993

STORM, 1990

MOHERES, 1991

Geomatic, 1990

SigmaView, 1992

GSLIB, 1992

RC², 1992

ODIN, 1990

STRATAMODEL, 1987

Discrete Smooth Interpolation, Mallet, 1989

FracMan, *~1990*

Stochastic Fracture Modeling

Multipoint Simulation, Strebelle, 2002

Plurigaussian, 1997, Le Loc'h

Schlumberger acquires Technoguide 2002

Auto History Matching, 2000

RML, 1999

Petrel, 1996

Smedvig becomes Roxar (RMS), 1999

Smedvog acquires Geomatic, 1997

JOA 1999

ROXAR (Emerson 1999)

Technoguide 1996

UVT Space/Time Math Framework Mallet, 2004

Genetic Stochastic Models

Auto fitting of Spatial Models

Volume Modeling

Ensemble Kelman Modeling

Uncertainty Quantification in fractured reservoirs

Inverse Modeling Problems

Petrel E&P

Baker acquires JOA, 2009

Paradigm acquires EDS (goCad), 2006

Landmark releases V1 DecisionSpace, 2006

Geostatistical Reservoir Modeling, Deutsch and Prycz, 2014 Gridless Modeling

Big Data Analytics

Integration Geostatistics and Statistics

Geostatistics and unstructured grids

gstatspy in Python, 2019

gstat, in R, 2016

RGeostats., MINES ParisTech, 2014

pygeostats in Python, 2019

Emerson Acquires Paradigm, 2017

Petrel Shale

JewelEarth/Baker 2014/2015

SKUA (Paradigm)

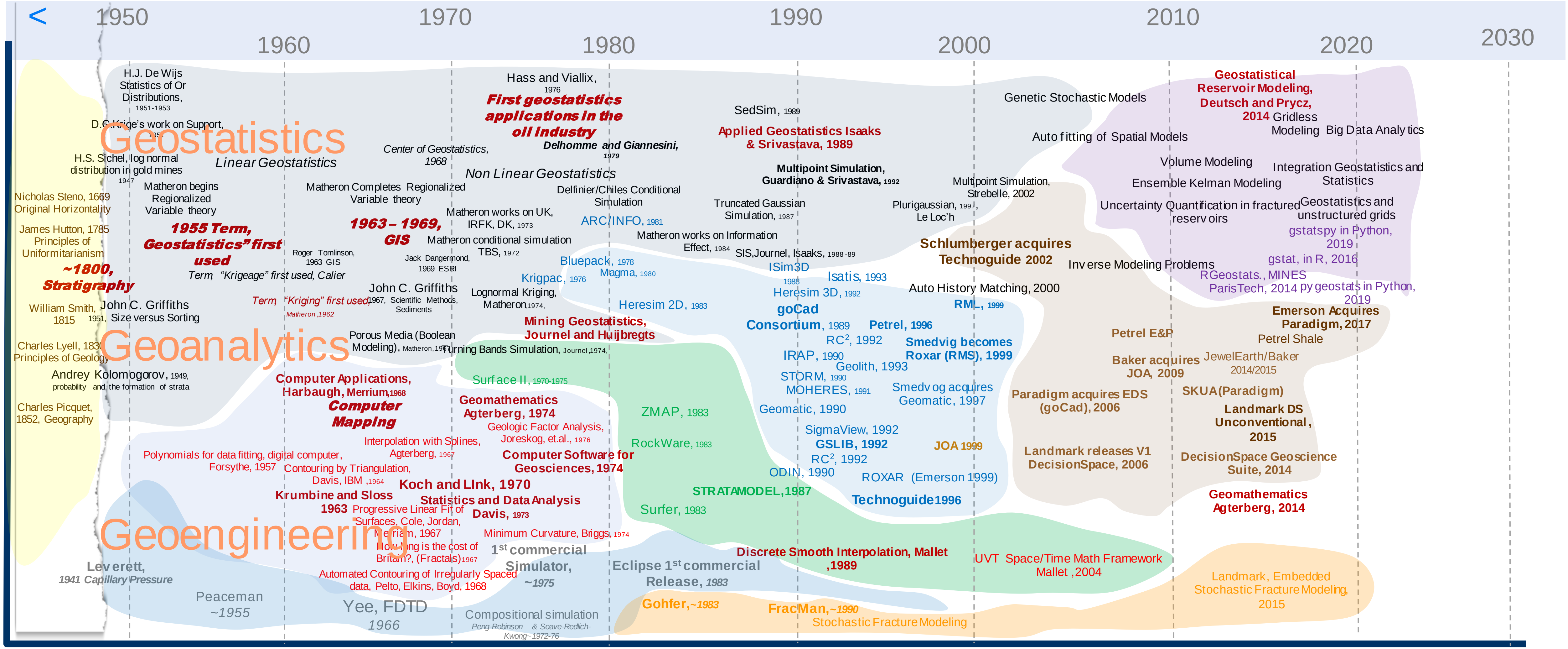
Landmark DS Unconventional, 2015

DecisionSpace Geoscience Suite, 2014

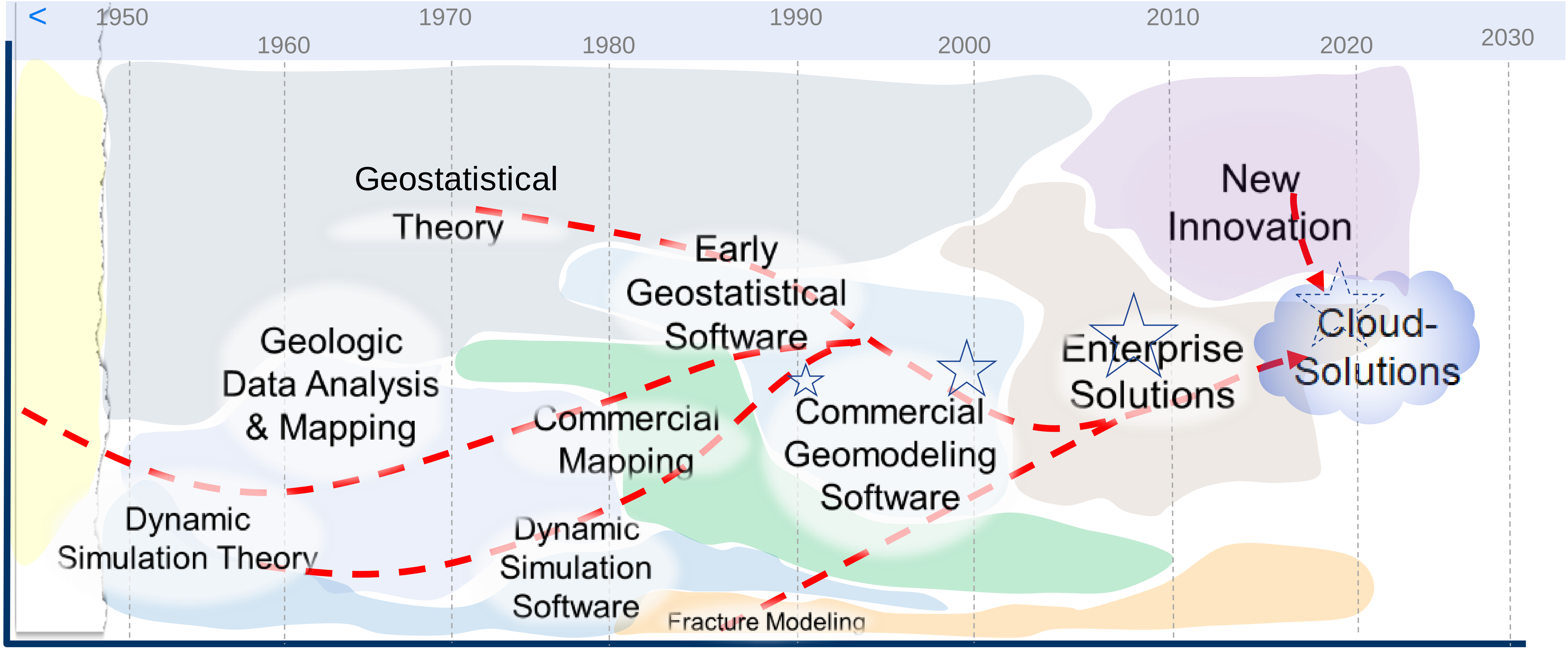
Geomathematics Agterberg, 2014

Landmark, Embedded Stochastic Fracture Modeling, 2015

How we got to where we are… Unsupervised Clustering



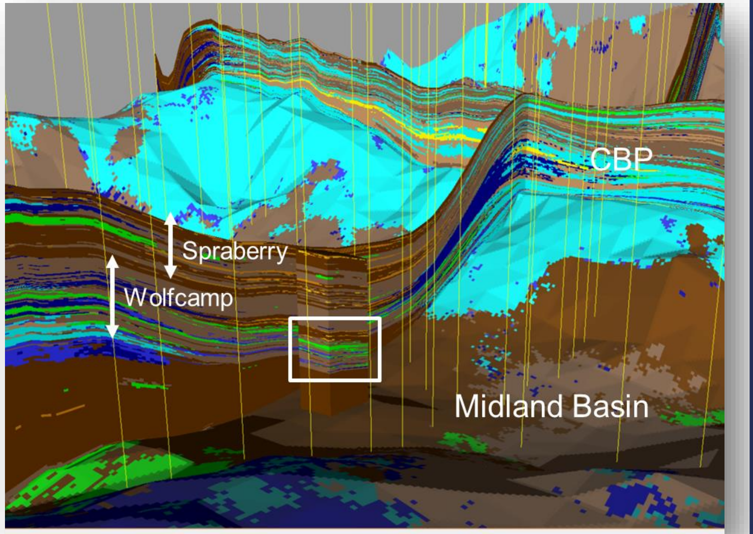
How we got to where we are… Trends



Applications

Oil and Gas: 3D Permian Basin (Wolfcamp Model)

86,000 sq mi
~12,000 cu mi

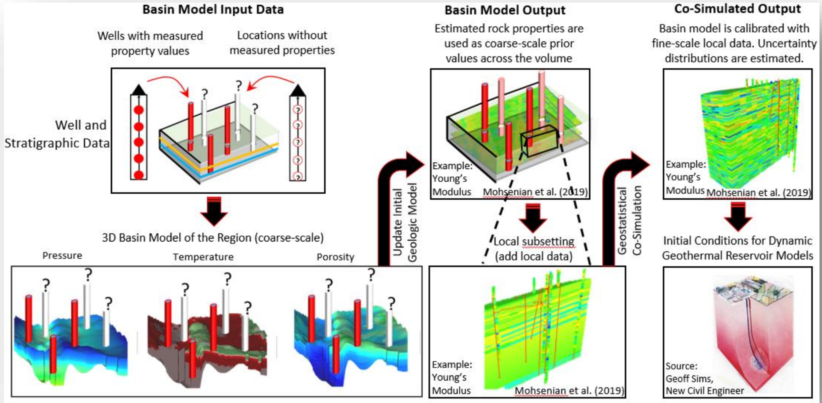


- Geostatistics
- CNN ML (Facies)

Evens, et. al, URTEC-2019-338-MS

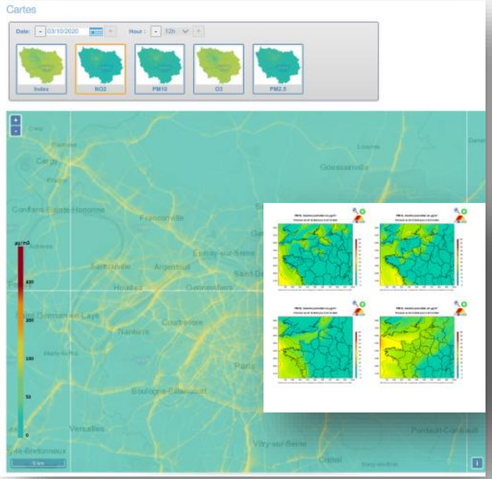
Geothermal Modeling

- Geostatistics
- Basin Model
- Sparse Data, ML



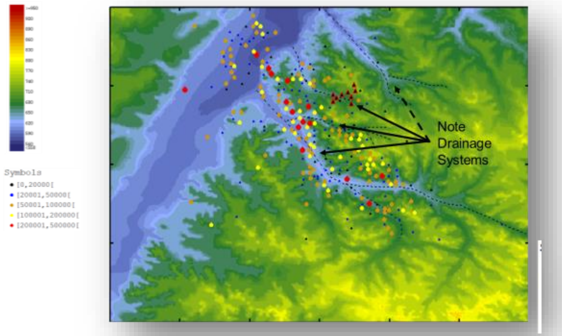
Yarus, et. al, DOE GTO, 2020

Real-Time Air Pollution Index (NO2,PM10,O3, PM2.5, …)



Air Parif
(https://www.airparif.asso.fr/indices/horair)

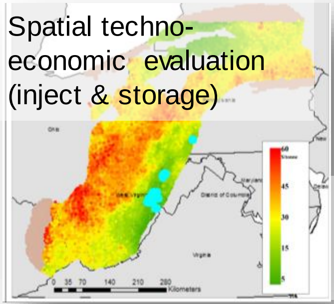
Surface Modeling, Stream Drainage & Subsurface Fracture/Fault Prediction

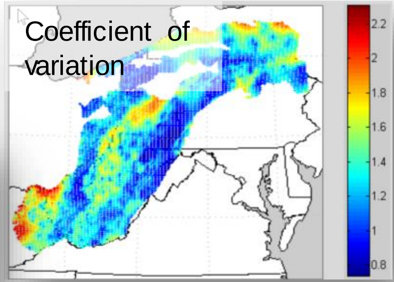


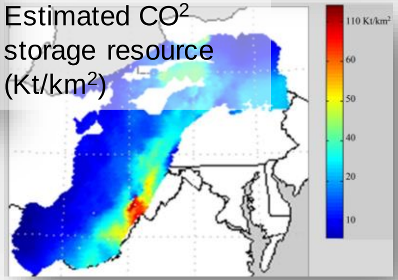
- Geostatistics
- CART ML

Yarus, et. al, 2003, AAPG

CO^2 Sequestration Oriskany Formation







Popova, 2014 Ph.D. Thesis

Industry Challenges

Computational Environments

- Large Model Sizes and Big Data
- Enterprise → Cloud-Based, (“Lift and Shift”)
- Increase CPU Speed & Memory
- SaaS and PaaS/IaaS
- Domain education on HPDC ++

EM infrastructure and design

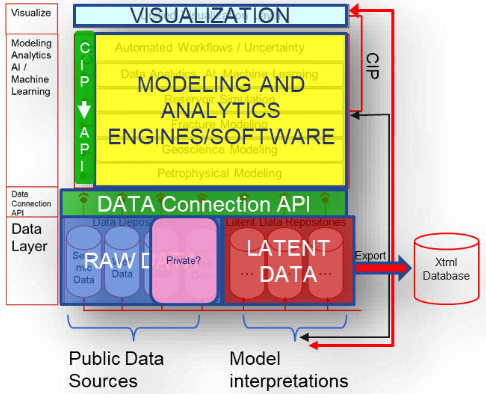
- Gridless modeling (enablement for:)
- Seamless scaling
- Real-time updating and monitoring of EM
- Integration with proximal products
- Automation

Uncertainty Assessment

- Redefine: Space of Uncertainty
- Sparse and missing data, data cleaning, economics

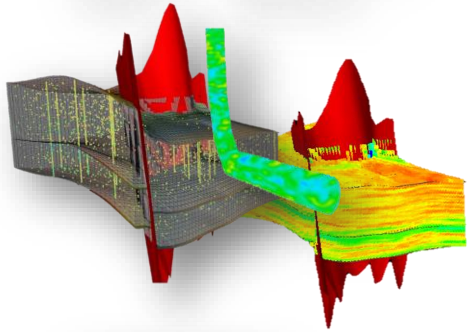
Think:

Software re-design to fit newer computational systems and services



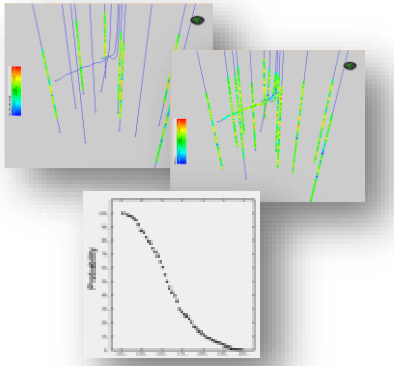
Think:

Automated – and real-time modeling that is gridless, static and dynamic



Think:

More inclusive space of uncertainty



Considerations for CO^2 Sequestration

Models considering CO^2 injection or the spatial extent of injected CO^2 require information about the reservoir properties that are often unknown or oversimplified

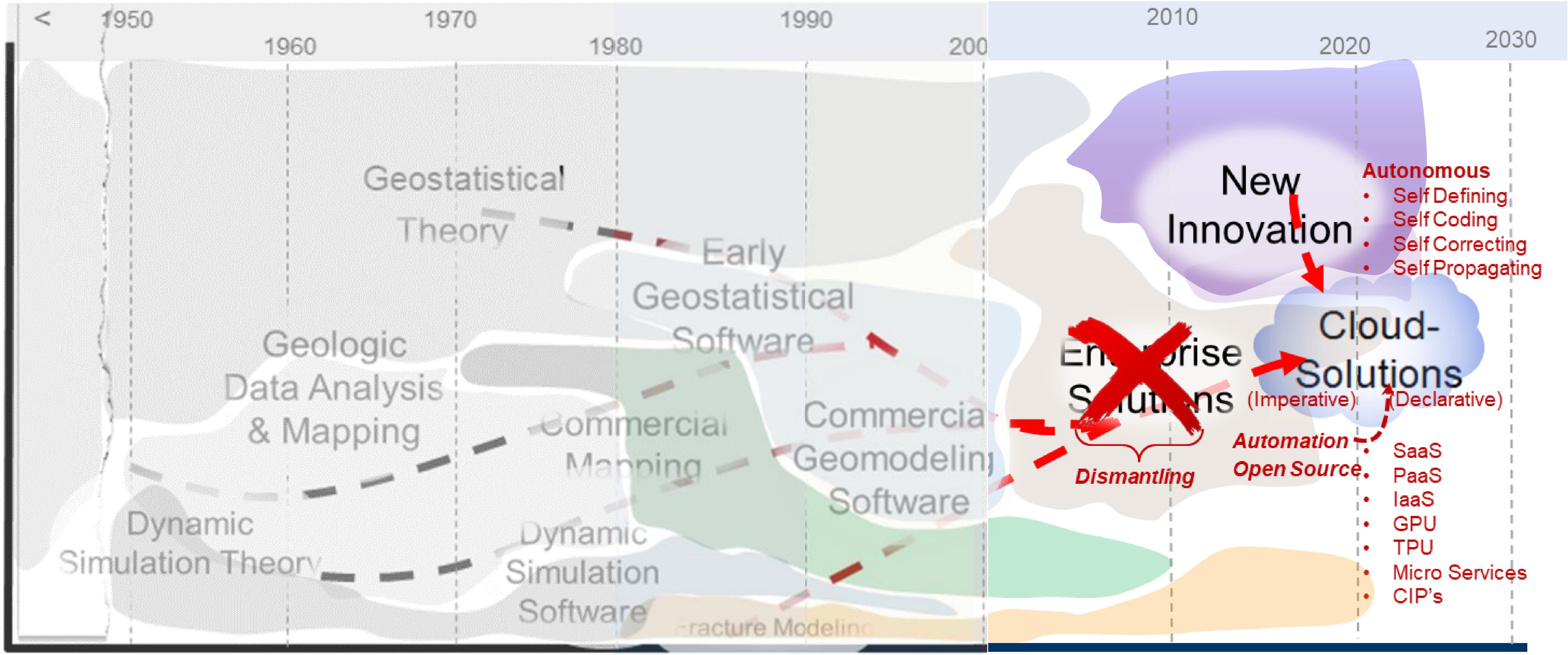
- <u>Caprock Characterization</u>
- <u>Deep saline formations:</u>
- <u>Oil and Gas Reservoirs (sandstone, coalbeds, shale, carbonates, …)</u>

Common EM Challenges:

- Cap and container characterization (faults, fractures, facies, petrophysics)
  - ➢ Standard geostatistical earth modeling
  - ➢ Not often done in 3D
- Cap and container post injection chemistry and geomechanics
  - ➢ How has the formation changed post drilling, injection (CO^2 and/or O&G completion, P&A, …)
  - ➢ Forecasting Model: Not generally done

(Ghanbarnezhad, et., al, 2016 IntechOpen)

How we got to where we are… Looking Forward



Selected References

1. Yarus, J. M., Srivastava, R. M., Chambers, R.L. (2006). Geologic Success but Economic Failure; Uncovering Hidden Problems Using Recursive Partitioning, American Association of Petroleum Geologists Annual Meeting, Houston, Texas, Abstracts.
2. Olga H. Popova, Mitchell J. Small, Sean T. McCoy, A. C. Thomas, Stephen Rose, Bobak Karimi, Kristin Carter, and Angela Goodman. (2014). Spatial Stochastic Modeling of Sedimentary Formations to Assess CO^2 Storage Potential, Environmental Science & Technology 2014 48 (11), 6247-6255, DOI: 10.1021/es501931r
3. Yarus, J. M. Carruthers, D. (2014). Combing Geostatistical Reservoir Modeling With Classical Basin Modeling Techniques to Identify Sweet-Spots in Unconventional Reservoirs, Extended Abstract, Presented at the AAPG Annual Convention and Exhibition, Houston, Texas, April 6 – 9, Search and Discovery Article #41362
4. Celia, M. A., S. Bachu, J. M. Nordbotten, and K. W. Bandilla (2015), Status of CO^2 storage in deep saline aquifers with emphasis on modeling approaches and practical simulations, Water Resour. Res., 51, 6846–6892,doi:10.1002/2015WR017609
5. G Moghanloo, Rouzbeh & Yan, Xu & Law, Gregory & Roshani, Soheil & Babb, Garrett & Herron, Wesley. (2017). Challenges Associated with CO^2 Sequestration and Hydrocarbon Recovery. 10.5772/67226.
6. Evans, KCS, J Yarus, E Mohsenian, J Montero, J Zhang, A Bromhead (2019). Leveraging Regional Geology and Sequence Stratigraphic Concepts at Field and Reservoir Scales: Building More Reliable Earth Models Under Sparse Data, Unconventional Resources Technology Conference, Denver, Colorado, 22-24
7. Adelman, Melanie, (2019). Managing Sparse Data and Missing Values in Unconventional Reservoirs, Masters Thesis, University of Houston *(to be published in 2021).*

InnovationXLab CarbonX Summit

Carbon in the Digital Era: Artificial Intelligence & Machine Learning

THANK YOU!

Please submit your questions in the Zoom Q&A function!

Looking for additional conversation and networking?

Join us in the Peer Connections Lounge after the next panel!